Stopped vehicle Hazards – Avoidance, Detection, And Response (SHADAR)

SHADAR Project Final Report

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Stopped vehicle Hazards – Avoidance, Detection, And Response (SHADAR)

D1.1 SHADAR Project Final Report

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Executive summary

This is the final report from the CEDR 2019 Safe Smart Highways project "SHADAR" which aimed to reduce risk of collision with stopped vehicles through research on detection and reporting, response by traffic managers, and the behaviour of road users before and after these incidents. This report summarises the findings of SHADAR research, which are provided in full in the set of SHADAR deliverable reports D2.1 to D6.1.

Detection of stopped vehicles

A study on the current state-of-the-art of detection showed that almost all countries use various types of fixed sensors that can detect stopped vehicles, but dedicated stopped vehicle detection on open highways is limited, with some coverage of radar and video analytics. Detection through connected vehicles is less widely applied, although Waze is used operationally in a few countries.

Little quantitative evaluation of detection technology has been published, other than from limited trials. Detection rates achieved in trials of dedicated stopped vehicle solutions are high (>80%), while anecdotal evidence on other methods suggest relatively lower rates.

Methods exploiting connected vehicles for direct detection currently have relatively low coverage in the vehicle population so produce relatively lower detection rates, but coverage and therefore usefulness for stopped vehicle detection is increasing.

eCall, because it is fitted to all newly type-approved cars and light vans, is increasing rapidly in coverage of the vehicle population. In addition to the voice calls, eCall sends a data packet that can be processed automatically, eliminating delays, yet few countries currently use this data in traffic operations. SHADAR found that eCall activations designated as automatic indicate a very strong likelihood of a real incident. Manual eCall activations have a higher false alarm rate but can still contribute useful information, especially when processed and fused with other information. eCall data can facilitate lookup and presentation of additional vehicle data such as vehicle type and propulsion type that can improve the efficiency of response.

eCall is not the only source for stopped vehicle alerts from connected vehicles. Standardised cooperative intelligent transport system (C-ITS) capabilities include stationary vehicle identification and warning, but still have low uptake beyond pilot projects. Several data providers offer traffic data commercially, and now the Data for Road Safety initiative aims to make safety-related traffic information available for all road users in Europe. Analysis of a large Waze dataset from the Netherlands showed that detection rate is high, alerts are faster on average than those recorded by the national data portal in the Netherlands, and they cover a much larger road network.

Rotating radar used for stopped vehicle detection has additional potential including lane determination, pedestrian detection, and contribution of further indicators to increase accuracy of event detection in a data fusion system.

Given the number of different fixed and mobile detection sources, each with their own strengths and limitations, there is potential for data fusion to achieve better overall performance than can be provided by any one source. SHADAR showed how the performance of a stopped vehicle detection fusion system can be characterised, using probability theory, so that an authority can understand the value of investment in the sources and their fusion. Better performance comes by fusing sources that behave independently. The confidence in any fused alert can be calculated and used to influence reporting and prioritisation for an operator. A study applying data fusion to real stopped vehicle data from two sources showed that each source was missing true stopped vehicle events that were detected by the other source. Even without the expense of a full ground truth study, the analysis of two sources together provides knowledge about the performance of each source which was not otherwise apparent. Using these sources together in a data fusion system would have increased the detection rate and reduced the false alarm rate when compared with using a single source.

Road user behaviour

Virtual reality simulations were developed in which participants encountered a stopped vehicle in different positions, weather conditions and traffic situations. When the participants had no prior indication that the incident was known to authorities or services, they indicated a wide range of behaviour. Although most participants would try to pass by the stopped vehicle in a safe manner, others would exhibit dangerous behaviour such as driving at walking speed and trying to get in contact with the person in the stopped car when passing by, or stopping in front or next to the stopped vehicle. There was no common knowledge about how to behave when a stopped vehicle is unexpectedly encountered. There was no unanimous opinion on whether to call for help in the event of a stopped vehicle, or who to call in such a case. Weather and traffic conditions seemed to have little impact on behaviour.

A further set of virtual reality simulations provided the participants with some kind of warning about the stopped vehicle: message sign settings, on-board display, radio traffic news, and an impact protection vehicle upstream of the stopped vehicle. The information via message signs was favoured by participants. Nearly all participants respected the information and intentions of stopping to help and report the incident almost disappeared due to participants understanding that the incident is already known. Warning given at 700m or less before a stopped vehicle tended to be considered insufficient notice.

Response to stopped vehicles

A study on the current response methods showed that processes in each consulted country have a similar pattern of discovery, warning, verification, firm response action, and communication, but with differences in detail. Of the various organisation, cognitive and physical factors that support control room response, the organisational factors have the greatest influence, shaping how the control room operates, with consistency of incident management processes. Integrated stopped vehicle detection increases situational awareness and shortens the time to respond.

Consulted roads authorities all confirm that using multiple sources can provide verification and increase confidence in alerts. Operator trust can be supported by early participation of operators in the introduction of new technology. For the richer information achievable from a data fusion system, the use of colour, position, and numeric confidence in the operational user interface were all considered useful tactics to support response prioritsation.

Outside the control room, addressing the knowledge and understanding of drivers can help reduce the hazards from stopped vehicles, and could provide greater compliance with traffic management measures.

Connected vehicles and devices can provide an additional channel to disseminate information, but consistency with road operator information is important. Specific cooperation patterns for public-private cooperation have been proposed, but our research suggests that the patterns that go beyond data exchange are likely to require ongoing funded effort to provide benefit.

Next steps

SHADAR results suggest both action and further research. Action can be considered by each national road authority individually using the key findings according to the needs and priorities of the country. This report also identifies several further research topics suggested by the SHADAR results.

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1 Introduction

1.1 Purpose

This is the final report from the CEDR 2019 Safe Smart Highways project "SHADAR" (Stopped vehicle Hazards – Avoidance, Detection, And Response), funded by national roads authorities in Austria, Belgium (Wallonia), Finland, Germany, Hungary, Ireland, the Netherlands, Sweden, and the United Kingdom.

The CEDR 2019 Safe Smart Highways programme sought to reduce the risk of collisions with stopped vehicles[1]. The SHADAR project responded to this need through research on detection and reporting of stopped vehicles, response by traffic managers, and the behaviour of road users before and after these incidents.

The SHADAR final report is required to meet two main purposes:

- it provides a summary of key findings from all SHADAR research deliverables
- it is a management report which also records all dissemination activity and lessons learned.

The details of SHADAR research results can be found in the other SHADAR deliverables which are identified in the methodology section below.

1.2 SHADAR research methodology

The SHADAR methodology was to consider the main strands of detection, response, and road user behaviour, starting by establishing the current international state-of-the-art then progressing to consider potential improvements. The research was organised in work packages as shown in Figure 1.

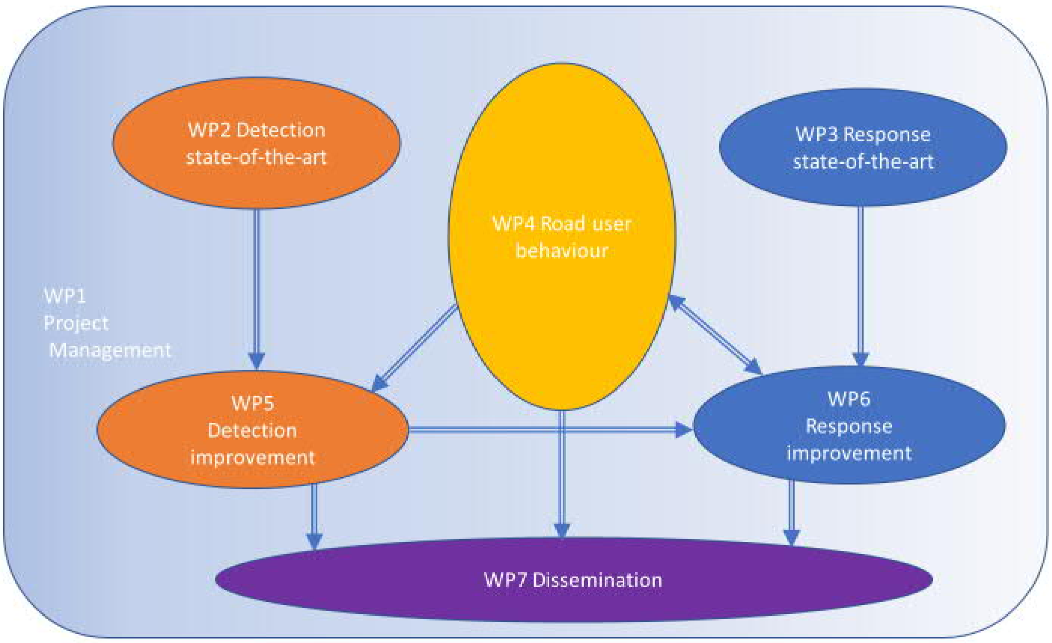

Figure 1 SHADAR methodology expressed as work packages

Project partners (who included companies working on stopped vehicle detection) pooled their knowledge on detection methods, supplemented this with further literature study, and conducted a survey on their usage by European national road authorities. The output was the report **D2.1 "Stopped vehicle detection and reporting – current methods"**.

On the subject of responses by road operators, project partners carried out a literature review, a series of semi-structured interviews with six responding organisations, and one deeper case study of control room operations. The output was the report **D3.1 "Response current practices"**.

Concurrently the project researched road user behaviour. A set of interviews with road users in three countries gathered information on the range of relevant behaviours. Scenarios were then designed in which the motorist would encounter a stopped vehicle in various contexts and conditions. Virtual reality simulations of driving through these scenarios were prepared and experiments were conducted with volunteers from three countries. Two sets of experiments were conducted, each with 80 volunteers all undertaking multiple simulated drives. In the first set, there was no kind of road authority response to alert the driver to the presence of the stopped vehicle. In the second set, various kinds of road authority response or warning information were presented before the stopped vehicle was encountered. Participants responded to sets of questions and results were analysed and reported in **D4.1 "Results of the behavioural simulation study“**.

Through knowledge of the partners and the results of the state-of-the-art study on detection, potential improvement areas were identified. The project performed further research on using eCall data, by study of specifications, limited available data, and statistics, and experiments with the limited available data. Experiments were performed with data captured from radar detection equipment to explore the potential for increased precision and earlier detection. The potential of emerging detection methods was analysed through study of available statistics and other relevant research results. The potential of data fusion was explored by derivation of formulae and approaches for fusing data, illustrated by numerical examples, and a study of real data from a European highway where two different detection technologies had been used, concurrently and co-located. To explore how multiple and fused alerts could be best reported to operational staff, the project defined a number of scenarios in which various permutations of detection information would be available, and developed user interface mock-ups to show how the information might be presented. The output compiling all this varied detection research was the (lengthy and detailed) report D5.1, which was distilled into report **D5.2 "Stopped vehicle detection and reporting : Summary of research results"**.

The study on current methods of response had not suggested significant scope for control room process improvements. The response improvement research therefore focussed on whether and how operational response would be improved by additional kinds of information that could be available from new detection methods and data fusion. The scenarios and user interface mock-ups produced in detection research were discussed in a set of interviews with operational representatives from four national roads authorities. A separate set of interviews with road authorities analysed the potential for increased cooperation with private sector in-vehicle services providers to provide integrated traffic management. Analysis of the interview findings formed the report **D6.1 "Improving responses to stopped vehicle incidents"**.

2 Key findings of SHADAR research

2.1 Stopped vehicle hazards

These events appear to be relatively common. Numbers of recorded breakdowns on highways vary across Europe but range from thousands per year to tens of thousands[2] per year per country. Breakdowns are just one reason why a vehicle may stop; others include collisions, obstructions, and even unjustifiable personal decisions by drivers.

Past analysis of collisions resulting in people being killed or seriously injured[3] showed stopped vehicles to be the source of 1.6% of all fatal and serious accidents. A stopped vehicle event that leads to a collision obviously has a serious socio-economic impact. An assessment from 2019 estimated an average cost of approximately €3 million from each fatal road accident[4].

2.2 Stopped vehicle detection – current state

Results of the SHADAR survey on current stopped vehicle detection methods are summarised in the table.

Method	Usage
Phone call	Use reported in most countries (probably used in all). Some have emergency roadside telephones; others rely on private calls.
Social media	Waze is used in several countries. At least one country uses a textual social media analysis service to detect emerging traffic problems.
Traffic officers / road operators	Multiple countries have dedicated traffic officers who may report stopped vehicles; in other countries the police may perform this role
CCTV / video cameras	All countries have at least partial CCTV coverage and use this for verification of potential stopped vehicle events.
Automatic incident detection cameras	These are used in tunnels, and in a few cases on selected open highways, and in trials.
Thermal cameras	Some usage in tunnels and minor local usage.
Loops dedicated to standstill detection	Some usage on special sites such as breakdown bays.
Loop detection (high density <100m)	Used in tunnels and special rush-hour lanes. Except for the dedicated loops covered above, loops are detecting congestion and slow-moving traffic rather than stopped vehicles directly.
Loop detection (low density)	Widely used.
Radar	Rotating radar dedicated to stopped vehicle detection is used in increasing portions of the motorway network in one country. In other countries radar is used for traffic incident detection especially on bridges and in tunnels.
LiDAR, Bluetooth, Wi-Fi	No reported usage for stopped vehicle detection. (These were included in the survey due to potential and/or use in other ITS applications.)
Acoustic	Used in tunnels in one country (and trialled in another).

Floating vehicle data	Floating vehicle data purchased from the private sector is used operationally in at least two countries, plus further trials.
Cooperative ITS	Deploying in one country (and in R&D trials in further countries).
eCall	Although eCall is present in all countries considered, only 3 countries use eCall data directly in traffic operations.

Almost all countries use multiple methods that rely on human sight, and multiple types of fixed sensors installed to detect stopped vehicles, although dedicated stopped vehicle detection on open highways is limited, with some coverage of radar and video analytics. Detection through connected vehicles is less widely applied, although service providers offer relevant products as shown by responses to a further survey of private sector providers, and Waze is used operationally in several countries. Beyond those similarities, the difference in approach across countries is notable.

Stopped vehicle detection equipment, systems, methods, or services can be characterised by several metrics. Important performance metrics that are widely used are: detection rate, false alarm rate and time-to-detect. There is commonly a trade-off between these metrics: by making equipment more sensitive, it may be possible to increase the detection rate, but possibly at the expense of false alarms, which may be decreased at the cost of increased detection time. For fixed equipment spatial coverage is also very important, with the average spatial coverage per detector determining the number of detectors and therefore the overall cost, which includes installation and maintenance. Different kinds of detection each have different properties that affect performance, reliability, and life span. The performance of methods can be influenced by conditions including density of traffic, weather, lighting, infrastructure characteristics (including number of lanes, curvature of the road) and surroundings (including vegetation, thermal objects) or even the substructure of the road.

Little quantitative evaluation of detection technology has been published, other than from limited trials. Detection rates achieved in trials of dedicated stopped vehicle solutions are high (>80%), while anecdotal evidence on other methods suggest relatively lower rates. Methods that sense effects on traffic are dependent on minimum flow levels, so they produce lower average detection rates across all flow conditions. Methods exploiting connected vehicles for direct detection currently have relatively low (but increasing) coverage in the vehicle population so produce relatively lower (but increasing) detection rates. Human reporting of bystanders, social media and traffic officers obviously have lower overall detection rates due to their lower overall spatial coverage on the road network, although individuals may have perfect detection rates within their own spatial coverage. Methods that detect directly are typically faster than methods that detect indirect effects on traffic and methods that rely on human reporting.

The SHADAR survey also asked about research on the potential of stopped vehicle detection to reduce risk of collision. No research directly addressing that topic was found, but instructive related research[5] was shared by National Highways in UK. Individual risks such as “vehicle stops in running lane” have been quantified in the wider context of known road operating regimes with various known controls and countermeasures in place. Compliance with instructions such as signalled lane closures has been found to be high (99%), which suggests risk reduction potential from detection that leads to signalling. Loop-based incident detection with automatic signalling was considered to reduce accident rates by between 9% and 13%. When introducing stopped vehicle detection, the level of risk reduction would clearly depend on the previous level of facilities available and the measures available to respond to the detected incident. The roads where there is currently no detection will tend to be the same roads where there is no signalling infrastructure, and further data would be required to quantify the impact of detection and warning through connected vehicle services on those roads.

2.3 Stopped vehicle response – current methods

The traffic management response is informed by many elements including the nature of the information received, timeliness of the information, and the internal processes of traffic management operations. Processes in each country consulted have a similar pattern to Figure 2, but with differences in detail.

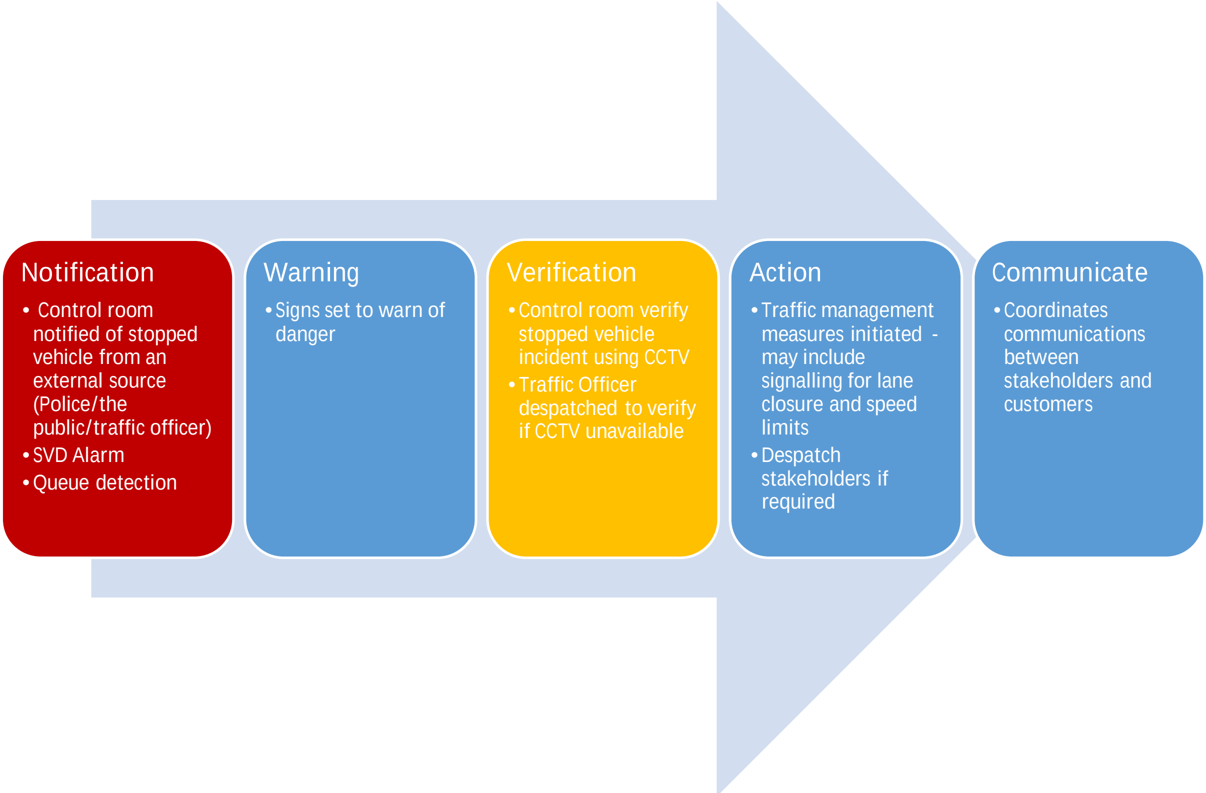

Figure 2 Control room processes in response to a stopped vehicle

Our interviews identified organisational, cognitive, and physical factors which support the control room in effective response to stopped vehicles in live lanes, to a greater or lesser extent. Through the discussions, it was concluded that the organisational factors have the greatest influence within the control room, which safeguard its functions by shaping how it operates both internally and externally, ensuring a consistent approach is followed, regardless of incident type. Organisational procedures also limit the influence of cognitive factors, identified within the literature review, which could potentially deviate from protocol.

Organisational procedures also drive forward the advancement of efficiencies and improvements through a continual process of development. These result in procedural changes and / or new technologies, which ultimately deliver benefits to motorists through a reduction in delay times as the control room is able to respond faster to stopped vehicles.

Both the primary research and the literature review identified the introduction of stopped vehicle detection (SVD) technology as providing operators with a greater understanding of what is occurring on the network, with enhanced levels of situational awareness and subsequent procedural response decisions compared to sections of the network where operators must look for incidents following external reports. Without SVD, the links and sequences of detection and reporting are complex, with different contact methods, procedures and technologies to alert the operator to a possible stopped vehicle. Greater complexity of communication and system links results in time delay when detecting, reporting, and responding to the event by control room operators.

When SVD is introduced to the control room, organisational factors play an integral role in the successful integration of the technology into operations. For example, excessive SVD false alarms can affect the cognitive factors which facilitate the efficiency of the control room, as operators disengage with and distrust the technology. Sufficient user testing with operators is crucial to addressing this, as it secures buy-in and empowers operators to identify improvements which enable the successful integration of the technology into the control room. Training, refresher training, and on the job experience ensure operators have the expertise to maximise the benefits of the SVD investment.

Control rooms with SVD also have a greater understanding of the incidents that may quickly become non-events, data which was unavailable prior to introduction of radar detection technologies. This could assist roads authorities to develop an understanding of why drivers stop in live lanes and inform future approaches which influence this behaviour whilst minimising the risk to other drivers.

Outside the control room, addressing the competence and capabilities of drivers through campaigns and legislation can support the effectiveness of the control room response in the long term, as drivers have a greater understanding of how to behave if their vehicle stops. Real time messaging to other drivers on the network, with supporting information as to why speed limits have reduced or lanes have closed, secures greater compliance to the traffic management measures initiated by the control room.

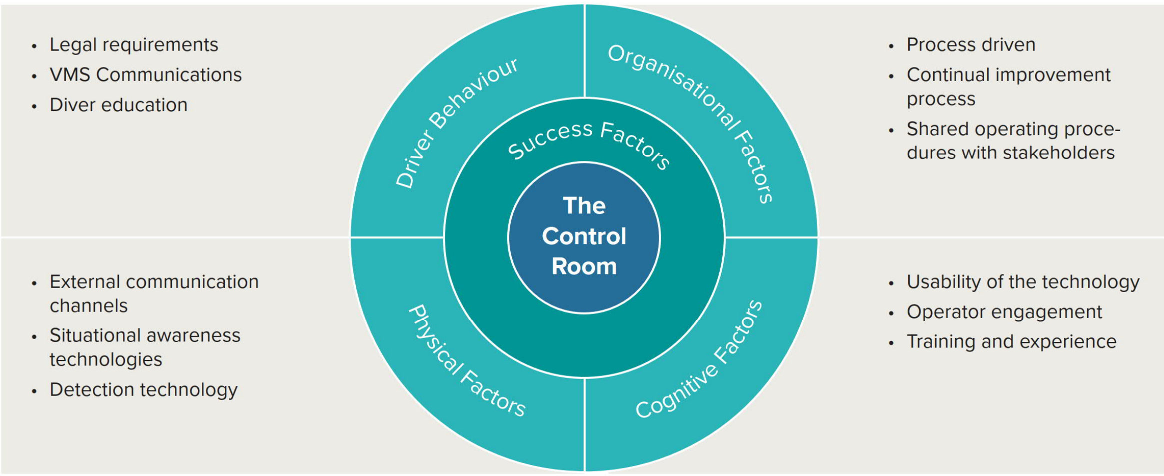

Figure 3 Control room success factors

2.4 Road user behaviour

Interviews with car drivers

Qualitative interviews in three different countries (Austria, the Netherlands, United Kingdom) explored how drivers inform themselves about traffic on highways, which information is considered as important, and their behaviour when facing incidents. The sample was balanced in gender and age and included both frequent and occasional motorway drivers.

The results show that different kind of information channels, such as SatNav, navigation apps, traffic news, and gantries are used. The most desired information is: what happened, where the incident is located and how does one have to behave. In the event of an incident on motorways, people claim they drive more carefully and more attentively, keep a greater safety distance, do not overtake, and reduce speed if a speed limit is displayed on gantries. In general, stopped vehicles on a motorway were perceived to be rare events. The interviewees were very uncertain how to behave properly in such a situation.

1st VR-simulation study

A stopped vehicle on a motorway was placed at different positions (1st/2nd lane, near an exit) under different weather conditions and traffic situations. The test person filled in pre-and post-questionnaires and were asked to comment on anything while driving through four scenarios. Questions regarding the situation and possible behaviour were answered. The simulation study was carried out in Austria, the Netherlands and the United Kingdom and included 81 test persons balanced in gender and age.

Figure 4 VR simulation example – approaching stopped vehicle

A **wide range of reactions and behaviours** in a situation where one is unexpectedly confronted with a stopped vehicle on a motorway was found. Most of the test persons would try to pass by the stopped vehicle in a safe manner, but also **some dangerous behaviour** such as driving at walking speed and trying to get in contact with the person in the stopped car when passing by or stopping in front or next to the stopped vehicle was reported. There was **no common knowledge** about how to behave correctly if you encounter a stopped vehicle. There was no unanimous opinion on whether to call for help in the event of a stopped vehicle, or who to call in such a case.

2nd VR-simulation study

Four new scenarios were developed, again with variety of stopped vehicle positions, weather, and traffic conditions. Unlike in the first set, these simulations provided some kind of information about the incident before it was reached. Four different information channels were used: Impact protection vehicle (IPV), gantries, traffic news via radio and information on a display in the middle of the dashboard. The information content differed and included general information about the incident, new speed limits, closed lanes, and general recommendations, how to behave.

Figure 5 VR simulations with warnings

The results show that the information via the gantries was seen as the best information source followed by the radio news. Apart from advantages of each information source also disadvantages were reported (e.g. visual information has the potential to distract, radio news can easily be missed, information must be received early enough). Nevertheless, within all four scenarios the test persons would mainly follow the information/recommendations given and alter their behaviour according to it. Stopping to help and reporting the incident was hardly mentioned during the second simulation as it was assumed that the incident has already been reported by someone.

Based on the results of the three parts of the driver behaviour research the following recommendations correspond to the opinions of the participants:

- Short and precise information should be given so that car drivers know where the incident is and how they should behave
- Information should be repeated as visual and audio information could be easily missed due to distraction
- Information should be multilingual and ideally not only in the language of the country. Symbols should be internationally valid and clear.
- Information should be given multisensory to appeal to as many senses as possible.
- Information should be given via as many channels as possible to get the attention of a wide range of road users.

The lack of awareness of how to behave suggests:

- The topic should be included in the driver's education.
- A traffic safety campaign (as used by National Highways in UK) can make drivers aware of risk and behaviour.
- Install or advertise a hotline so that drivers have a clear way to report such an incident.

2.5 Stopped vehicle detection - new and improved methods

The role of eCall in stopped vehicle detection

eCall (emergency call) is fitted to all newly type approved cars and light vans since 2018, with more types to come. It can be automatically activated, typically by air bag; or manually, by pressing an SOS button. A voice call is set up to a Public Safety Answering Point (PSAP), where an operator asks if assistance is required from the emergency services. This is similar to traditional 112 calls. However, eCall also contains a rapidly sent data packet, or Minimum Set of Data (MSD), that has vehicle ID, location and confidence in location, direction of travel, the number of occupants, fuel type and whether the alert was manual or automatic. eCall volumes are now increasing, with over 10,000 calls per month in the UK for example.

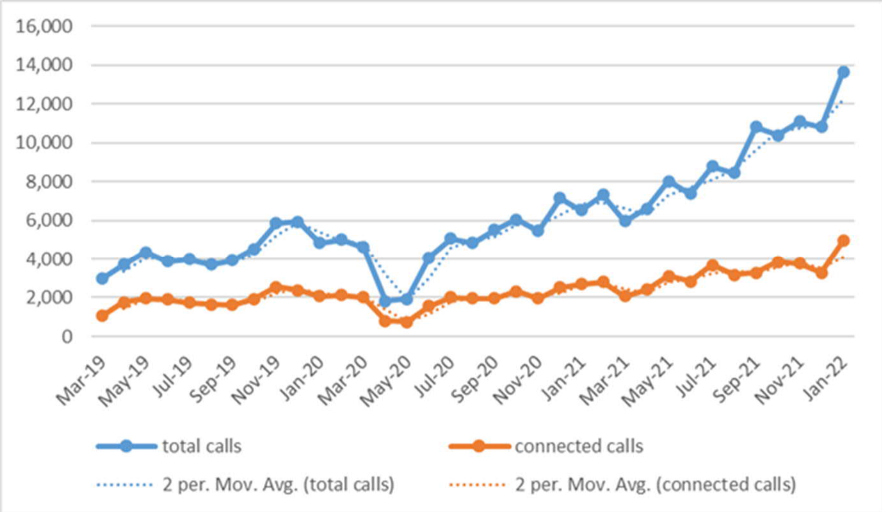

Figure 6 eCall volumes are increasing (UK example)

On receipt by PSAP, an eCall voice call will be answered by an operator, who will then pass the call and data to operators in different responders. European countries have a variety of patterns for how information in eCalls to PSAPs could eventually reach traffic managers. Study has shown that it is typical for each stage of this voice journey to take around 7 minutes on average, so it is common for chains of around **14 or 21 minutes to reach traffic managers**. In contrast, automated processing of the data packet could **reduce that time to seconds**. The MSD does not replace the voice channel but can provide an early warning.

The eCall makes the call using the emergency network. This prioritises the call over non-emergency calls. The MSD is no larger than a short text message to ensure it can be delivered in areas of low network coverage. Even if the voice cannot connect, the MSD can be delivered as long as there is emergency network coverage.

To assess the value of eCall data for stopped vehicle detection, we investigated reliability of data, false alarm rates, and accuracy. We found that automatic activations generated when a suitable vehicle condition occurs, such as high deceleration or airbag deployment, indicate a very strong likelihood of a real incident, and the MSD directly links the vehicle to the incident. The false alarm rate for these is very low as there is no human involvement. There are many scenarios where someone could manually press the button, such as to report a breakdown but also to demonstrate eCall in a car showroom. Hence manual activations have less confidence and need to be managed and filtered. 95% of eCalls are manually activated. Using limited available data and assumptions, we estimate that the false alarm rate for manually activated eCall may be in the order of 40%, while the false alarm rate for automated eCall may in the order of 5%. The confidence in an individual eCall alert is increased when more than one alert can be associated with the same physical event.

eCall data be processed in a workflow to filter, enhance, profile, and forward alerts:

- Filter – Reduce the number of false alarms passed to responders. Faulty units can be detected from unusual numbers of MSDs from a single vehicle, and further activations from that unit blocked for a period. Retransmitted alerts can be detected and withheld if the original alert is already known.
- Enhance – the MSD is intentionally a small dataset, but it can be used to look up further details in national vehicle registration datasets – for example the make and model, colour, kind of fuel/energy source, kind of transmission, number of doors – all facts that can be useful in emergency response. Point location data can be used in a map matching process to identify road number, direction, and reference points. Related alerts can be grouped.

- Profile – MSD data such as location confidence and whether the alert is automatic or manual, as well as enhanced data such as the vehicle type, can be used to influence priority of the stopped vehicle alert.
- Forward – provide the relevant alerts to the relevant emergency responders for the location - eCall activations can originate from any location – highways, country lanes, even fields.

eCall complements existing SVD methods to create a much wider coverage of the road network. So, if MSDs are processed together with other SVD alerts, a much richer picture can emerge. For example, a manual MSD has a low confidence of an incident, but a manual MSD with a radar alert provides a high confidence and provides vehicle details not available to radar.

Potential for improved radar detection

We explored several ways in which additional information could be provided by rotating radar systems to enhance the overall detection capability.

- The radar's azimuth resolution should support the determination of the lane of the stopped vehicle, not for the full operational range of the radar, but for approximately 150m of range. A small set of experimental results support this.
- Analysis of radar data for stopped vehicle events shows occurences of pre-stop and post-stop traffic speed reductions and queues, but so far not with sufficient volumes to clearly demonstrate correlation that could be used to support stopped vehicle detection.
- Radar can provide a limited but potentially useful classification of vehicle type.
- It was demonstrated that radar systems can identify and track pedestrians at the site of a stopped vehicle, which could identify potentially higher risk situations that may be worth prioritisation by the operators.

Waze

Although recent changes in provision of location data reduce any potential of textual social media, the private sector service Waze appears to still have potential. The potential of Waze for traffic management purposes was first considered in a previous CEDR study[6]. That study was illustrative rather than quantitative. SHADAR analysed the impact of Waze data in use by the national access point in the Netherlands (NDW), which collects data from multiple sources including Waze.

Using NDW historical data from 2020, over 120,000 unique NDW traffic situations relating to stopped vehicles were identified. These had been gathered and aggregated by NDW from multiple sources.

- Comparing NDW stopped vehicle traffic situation records to Waze alerts, 93% of the NDW situations can be matched in location and time to at least one Waze alert. This implies that the detection rate of Waze is high. Only 7% of NDW traffic situations were not detected by Waze.
- Matching in the opposite direction 31% of Waze alerts on the NDW network can be matched to an NDW situation. The 69% unmatched alerts may represent false alarms, very short stops, stops on the hard shoulder, or other reasons why NDW chose not to identify a traffic situation, or they may indicate untapped potential which NDW could have exploited.

The correlation between Waze and NDW information would only suggest significant potential of Waze as a detection source if the Waze alerts were often earlier in time than the corresponding NDW information. We therefore compared publication times for matching Waze and NDW information. We found that NDW published a situation message earlier than Waze for less than 0.2% of matched NDW situations. On average, Waze alerts related to stopped vehicles were published 1.5 minutes before a corresponding NDW publication.

The unmatched Waze alerts tend to be incidents with a relatively short duration, compared to the population of durations of matched Waze alerts, as shown in Figure 7.

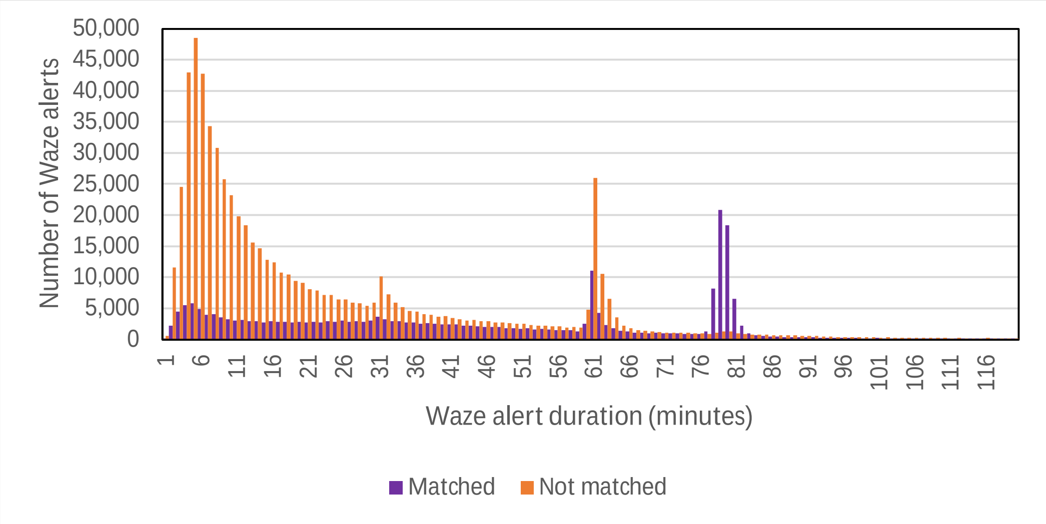

Figure 7: Distribution of the Waze alert duration

The majority of the unmatched alerts had a duration of 15 minutes or lower, whereas the distribution of durations of matched alerts is much flatter, showing durations frequently occurring up to 80 minutes. This pattern may be caused by short-term and low impact incidents that are reported in Waze but are not caught by the detection methods that lead to an NDW situation message.

Each alert in the Waze dataset also includes a confidence score, which is a a discrete number between 0 and 10 and serves as an accuracy measure based on user feedback. A higher score indicates more positive feedback from Waze users and is an indication that the alert corresponds with the real traffic situation on the road. The Waze data also includes a reliability score based on the experience level of the reporter. The general pattern is that Waze alerts that were matched to an NDW situation received more positive feedback from users compared to all Waze alerts.

Other connected vehicle sources

Methods using vehicle sensors have the potential for fastest detection and the richest supporting information but have relatively low levels of penetration in the vehicle fleet, although these are growing. Standardised cooperative ITS capabilities include stationary vehicle identification and warning, but in most countries C-ITS still has low uptake beyond pilot projects.

Several data providers offer traffic data commercially, and now the Data for Road Safety initiative aims to make safety-related traffic information available for all road users in Europe. Data that can be sent from vehicles includes manually and automatically triggered breakdown calls and eCalls, numeric sensor values from which a stop might be inferred, and external object detection which might include another vehicle stopped. A proof of concept was held in 2019-2020[7] which included the provision of safety-related traffic data by several companies. Evaluation focussed on the Netherlands – there the data included over 100,000 alerts of obstructions and over 80,000 alerts of vehicles in difficulty. During the trial the timeliness was examined between the registration of the incident by the vehicle and the available message at the national access point:

- 52% within 5 seconds
- 85% within 1 minute
- 96% within 5 minutes

For alerts of broken-down vehicles, the time-saving amount was up to 7.5 minutes compared with the available data from reported incidents in the public sector dataset. By joining the Data for Road Safety agreement and integrating with the available data sources, road authorities can access populations of connected vehicle data without fees. Coverage may vary across Europe, but the Netherlands study shows that at least in some parts of Europe the coverage is substantial.

Aerial imagery

Images from unmanned aerial vehicles and satellites could both provide more accurate information on location and vehicle type but have practical disadvantages. Satellites do not make sufficiently frequent passes for useful real-time stopped vehicle detection coverage. Aerial vehicles are expensive and suffer from weather conditions, reducing the effective range. They may become feasible for targeted applications.

Data fusion

SHADAR report D2.1 showed that there are several different technologies for stopped vehicle detection, with varying performance on important metrics such as detection rate, false alarm rate, independence from environmental conditions, coverage of the road network, precision of location, timeliness and data content. Analysis suggests that every source is outperformed by another source on at least one metric. On a metric such as data content, a fusion of data from different sources evidently has the potential to preserve the best from each source. For metrics such as detection rate and false alarm rate, SHADAR explored the hypothesis that fusion can improve these even beyond the best rates achieved by individual sources.

Machine learning has become popular through success in many contexts. Machine learning of raw sensor data holds technical promise but may currently be working against the market in which technology providers aim to optimise their own detection offerings rather than provide raw data into a larger fusion system. A more practical route today for a roads authority is to fuse the outputs from these technology providers. This could also be done by machine learning, but SHADAR explored a simpler statistical method which may give equivalent value.

No known current practical detection source is 100% accurate 100% of the time - every alert from every detection source can be considered to represent a probability of a real stopped vehicle event. The performance of a stopped vehicle detection fusion system can be determined using probability theory. Using detection performance on past examples to predict detection performance on future examples assumes that the past examples are representative of future examples; that is not a trivial assumption, but even if the past examples are not perfectly representative, and the forecasts not perfectly accurate, the technique can be useful.

For basic data fusion rules, such as alert if any source alerts, or alert if all sources alert, the detection rate (the probability of a real stopped vehicle event being detected) of a data fusion system can be expressed in terms of the detection rates of individual alert sources using standard probablity equations.

However, the false alarm rate (the probability that a stopped vehicle alert does not relate to a real stopped vehicle event) of a data fusion system cannot be derived simply from the false alarm rates of the individual alert sources – empircal data on simultaneous false alarms is needed.

An alternative fusion rule that can balance detection rate with false alarm rate is to alert if the probability of a stopped vehicle event is calculated to have exceeded a threshold. Using detection rates and false alarm data from the sources, the probability of any permutation of sources being a real event can be calculated. This requires assumptions about times to detect.

Approaches could range from simple heuristic time thresholds to more complex integration of probability distributions of detection times. Calculations of confidence as alerts occur can be refined by considering contextual factors such as weather and traffic state, if there is sufficient empirical data about detections and false alarms where such states are known. The confidence calculated for a fused alert need not be used to withold information from the operator, but rather to adjust its priority.

Analysis of detection rate, false alarm rate, and time to detect of fusion schemes should help a road authority understand which fusion rules are appropriate, which data sources should be integrated, and what performance may be achieved. Choosing a data fusion regime allows a choice between optimising the detection rate and optimising the false alarm rate. Better performance comes by fusing sources that behave independently. Sources with entirely different technical basis (such as eCall compared to radar) are likely to show high independence, while sources with some similarity (such as two methods detecting electromagnetic reflections) are unlikely to be entirely independent and may produce less improvement when fused.

Case study: application of data fusion to real stopped vehicle alert data

For a limited trial period in 2020-2021, two sensor-based stopped vehicle detection systems were employed on the same highway in Europe. Each system used a different detection technology. The exact location and nature of the sources has been anonymized; the purpose of this study is to explore the potential of data fusion, not to identify the performance of specific detection sources (which were both private trials in this case). Data fusion was not employed during the trials but afterwards to explore probabilistic data fusion techniques.

The detection data sources were not designed to support data fusion analysis so unsurprisingly were not ideal for that purpose. Correlating the sources required assumptions. Data fusion would be simplified if reporting and logging were designed with a requirement to support data fusion. Although this study did not have access to a complete record of ground truth, analysis can still derive information about each source, and about data fusion, which is not apparent from each individual source alone.

Apparent characteristics of the data sources before data fusion analysis

Data source “A” in our sample had 564 true positive stopped vehicle alerts and 23 false alarms, all verified by humans. The false alarm rate was therefore 4%.

Data source “B” was more difficult to interpret because results must be inferred from operational logs. With certain assumptions on how to interpret the operational log data, the false alarm rate was around 30%.

The detection rate for either source cannot be calculated or even estimated from that source alone, because neither data set says anything about true events missed.

Fusion of data sets

We performed matching of alerts across the two data sources, which required reasonable assumptions about time and location.

Inferred detection rates

The alert matches allow inferences about the detection rates of each source, which were not possible when considering each dataset in isolation. If we were to assume that between the sources, all stopped vehicle events were found, then the detection rates of each source can be calculated. That assumption may not be valid, so a detection rate calculated is a maximum.

	Source A	Source B
Inferred detection rate	36%	82%
False alarm rate	4%	31%

Before this analysis, the detection rates were unknown. Study of the sources together suggests that each source was not individually finding all true stopped vehicle events; for the first time, detection rates are inferred. Even without the expense of a full ground truth study with constant human vigilance, the analysis of two sources together provides knowledge about the performance of each source which was not otherwise apparent.

Applying data fusion in real-time

The table shows the detection rates and false alarm rates that could have been achieved by fusion regimes if they had been used operationally (again given a set of assumptions required due to lack of complete ground truth data).

	(max) DR	FAR
Source B alone	82%	31%
Sources fused (OR regime)	100%	27%
Sources fused (AND regime)	17%	1%

Using these sources together in a data fusion system with an OR rule (alert if either source alerts) would have increased the detection rate and reduced the false alarm rate (albeit higher absolute number of false alarms) when compared with using a single source. The severe “AND” (alert if both sources alert) regime almost eliminates false alarms but the expense of a much lower detection rate.

With a simple approach to detection times, where at the first receipt of an alert from either source no significance is attached to a missing alert from another source, and where if no alert from the other source is received after a further period it is assumed not to be coming, then the confidence in individual alerts is as shown in the table. Such knowledge could be used to influence the priority with which alerts are displayed.

Confidence:	Initially	Absence of other source confirmed	Both sources alert
Source A first	96%	49%	99%
Source B first	70%	56%	99%

Technology performance reporting

In a regime with several kinds of stopped vehicle detection sources and data fusion, a technology manager may want to see how each source is performing, especially since the impact of specific connected vehicle sources may grow or shrink over time as technologies and/or brands grow or shrink in popularity. Such data can also be used to inform incident analysis e.g. identifying road sections with high incident rates.

SHADAR produced mock-ups of report screens that could be used to support decisions on continued investment. The statistics that can be derived depend on whether ground truth data is available. Normally there will be no source of complete ground truth data because that needs special effort to collect (currently 24x7 human verification). Without complete ground truth, but with at least some operator verification of alerts, useful statistics can still be computed.

The SHADAR mock-ups were discussed in interviews with road authorities, who considered such performance management reports helpful for optimising existing technology and informing new or continued investment decisions. For the latter purpose, considered particulary useful were the number of cases where the specific source was the first to detect a real event, and the number of cases that the source was the only one to detect a real event.

2.6 Stopped vehicle response – improvement and best practice

From our interviews and wider research, potential solutions and related considerations were identified for three key areas: interacting with road users, fusion, and connectivity. Each would require tailoring for the context and current starting point of any single national road authority.

Interacting with road users

- As noted above, understanding of what to do when faced with a stopped vehicle in a live lane is lacking, and education through campaigns and augmented driver learning could improve behaviour, supporting traffic management response.
- Road users may contact emergency services, but reported delays between emergency calls and traffic management contact suggest potential for review and improvement of the processes and steps involved.
- Consulted road users desire short and precise information, repeated information, multichannel information, and multisensory information (seen and heard). The study was not at the level of scale or detail to scientifically distinguish specific parameters, but warning given at 700m or less before a stopped vehicle tended to prompt comments that this was not enough notice.

Harnessing fused data and new sources

SHADAR demonstrated through a series of scenarios and user interace mockups how new sources could be fused and presented to traffic management operators. Operators could:

- expand or collapse a group of alerts about one event to show or hide individual detection details
- understand priority through colour, position, and numeric confidence
- see additional information that can be gained from some sources, such as vehicle type, make, propulsion, and passengers
- see where detectors that would be expected to alert have not done so
- see integrated supplementary data sources such as road surface conditions and CCTV at the incident scene.

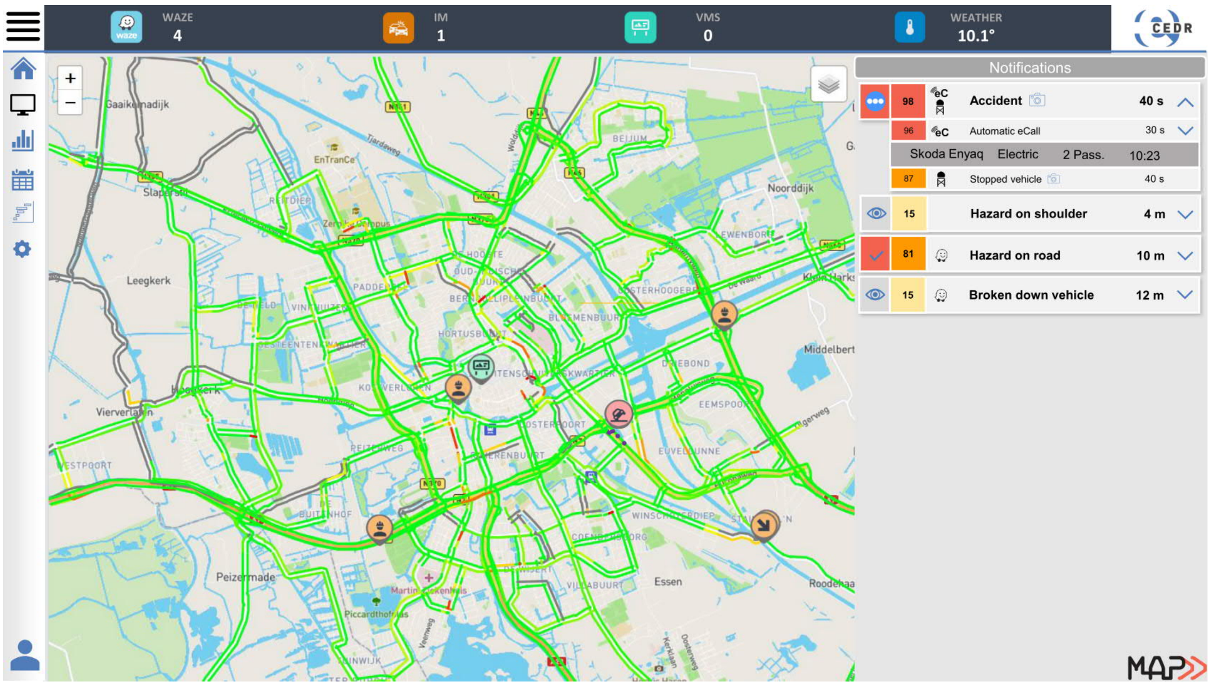

Figure 8 Illustration of richer information from fusion of multiple sources (right-hand panel)

Consulted roads authorities all welcome additional trusted information on stopped vehicles, and confirm that using multiple sources can provide verification and increase confidence in alerts. Operator trust can be supported by early participation of operators in the introduction of new technology. A data fusion system that derives the confidence in each alert brings the opportunity to present confidence information to operators and use it to prioritise response. The use of colour, position, and numeric confidence in the operational user interface were all considered useful tactics to support response decision-making.

Introducing new sources will change the overall detection rate and the false alarm rate experienced by operators. Agreement on operationally acceptable levels of false positives when fusing data should be considered. The operational tolerance of false alarms influences the choice of fusion regime and how confidence in an alert affects its presentation to the operator.

Enhancement to today's traffic management systems would be required to present new kinds of information, and to support the concept of statistical data fusion producing confidence for alerts. The concepts are not complex, but the practicality of change depends on the characteristics of each traffic management system.

While CCTV integration is considered useful, the integrated presentation of other data sources such as weather and road surface condition had a mixed response from operational stakeholders (due to the potential for distraction from more important information), which suggests it should be highlighted only in defined exceptional cases.

Connected vehicles and devices

Connected vehicles and devices can provide an additional channel to disseminate information as part of the NRA response, but it is important that in-car information reaching road user via private organisations does not conflict with what they see from the road authority's own channels including roadside signs and signals. Consistency will support trust by the driver and should encourage helpful behaviours such as compliance with NRA advice. Specific cooperation patterns for public-private cooperation have been proposed by the SOCRATES$^{2.0}$ project, but our research suggests that the patterns that go beyond data exchange are not likely to achieve sustained benefits without ongoing funding. The topic is further explored at the Traffic Management 2.0 initiative in which participation by road authorities is free of charge.

A separate idea at an earlier stage of readiness is standardised data communication between emergency responders en-route to an incident and vehicles involved in the incident. Benefit has been suggested by research and the first standard has been produced. The standard envisages communications both by voice and with sensors in the affected vehicle which can provide more information to the responders. Given the early stage of the specifications further research seems required to confirm value and viability.

3 Dissemination

SHADAR performed these dissemination activities:

- We proposed, designed and executed a special interest session at the ITS World Congress 2021 in Hamburg. The ITS World Congress is the premier global technical congress in the Intelligent Transport Systems domain. The organisation was uniquely challenging because of the uncertainty produced by COVID-19 and resulting travel restrictions which were changing frequently for some participants, and the uncertainty was further increased by the sensitivity of the topic. Some re-organisation and re-design was required. Nevertheless the session on 14/10/21 was well attended, generated useful discussion, and we received positive feedback from participants.
- We wrote and presented the paper "Stopped vehicle hazards: detection and response” at Transport Research Arena (TRA) 2022. The paper was accepted for inclusion in the published procedia, but due to administrative misunderstanding was not included. Not being bound by TRA copyright after all, we therefore published it as open full text on ResearchGate, where statistics show it is being read.
- Also at TRA 2022 we provided a video slide presentation which was shown on a display at the CEDR stand, and gave an in-person presentation at the CEDR stand. Overall TRA seemed to produce limited interest in our work compared to our experience at other events.
- We submitted a paper to ITS European Congress 2022, focussing on stopped vehicle detection. (To our surprise it was not selected for presentation, and no feedback was provided to explain that. Its quality appears adequate albeit it is mainly a review paper with some novel content that is not prominent.)
- We presented SHADAR results to a grouping of traffic managers in UK. 8 UK road authorities (national/regional/county/metropolitan) attended.
- We presented SHADAR results to CEDR working group Road Safety at Almere, the Netherland, October 2022.
- We arranged a speaking slot at Highways UK 2022 industry event. (This was then withdrawn by the organisers to make way for other strategic priorities.)
- We presented SHADAR road user behaviour results at the ICTCT conference (International Co-operation on Theories and Concepts in Traffic safety) in Györ, Hungary, October 2022, and gave virtual reality demonstrations.
- We presented results to the CEDR Programme Executive Board (PEB) in joint calls or meetings at roughly six-month intervals as set by the PEB, with one held as an in-person meeting.
- We engaged with the project SAFEPATH – the other project in the CEDR Safe Smart Highways call. Since dissemination of existing research is the focus of SAFEPATH it should provide a useful additional channel for SHADAR dissemination. After management calls we undertook a joint consortia workshop to allow each project to understand the other. Rather than SHADAR trying to contribute to SAFEPATH dissemination in a fine-grained way, the method preferred by SAFEPATH and agreed by both consortia and the CEDR PEB was for SHADAR to simply provide all approved deliverables to SAFEPATH for its use. We have done this for all explicitly approved reserch reports from SHADAR (at time of writing this does not include SHADAR D4.1 or D5.1/D5.2).
- Submission of article in German for ZVS (Zeitschrift für Verkehrssicherheit) – German-language peer-reviewed scientific journal
- Submission of paper for TOTS - Transactions on Transport Sciences – English-language peer-reviewed scientific journal.

- We wrote and submitted the technical paper "Fusion of stopped vehicle alerts" to the ITS European Congress 2023. (Mott MacDonald intends to present this paper as a post-project activity.)
- We wrote and submitted the technical paper "Harvesting stopped vehicle alerts from eCall data" to the ITS European Congress 2023. (Chiltech, or Mott MacDonald if necessary, intends to present this paper as a post-project activity.)

This set of dissemination activities differed in some cases from the set of possibilities noted in the original dissemination plan.

- Being aware of increased sensitivity around stopped vehicles on “smart motorways” in England, we discussed sensitivity with National Highways, who asked if we can restrict our dissemination to more restricted channels. In our view more restricted channels include NRAs and specialist scientific/research channels but not open industry publications or industry organisations. For this reason, we decided not to target a webinar organised through ITS-UK, nor an article in an industry magazine such as Thinking Highways.
- We had planned to target the European ITS Platform (EU EIP) or its successor. However when SHADAR results became available in 2022, the EU EIP had ended and the sucessor was still in discussion. We tracked the progress of the successor initiative, which had the temporary name the "Duplo Forum" and led to proposal development with the title "EPICS". At the time of writing EPICS is still a proposal, but if it succeeds then it could be a useful channel for future CEDR research dissemination.
- When we first became aware that we would not perform those planned dissemination activities, we planned to write a scientific journal paper and discussed this with the PEB. This plan was superseded by our two technical paper submissions to ITS Europe 2023, which we expect to create more awareness.

The SHADAR project team intends to disseminate further in the CEDR 2019 end-of-programme event in 2023 as a post-project activity.

4 Lessons learned

Since the research findings are summarised in section 2, this further section is restricted to other lessons learned by the SHADAR team of researchers about the process of running such a research project.

Every partner in the SHADAR supplier team participated in a project review workshop on 5/1/23, in which we discussed and recorded:

- What went well (what we liked, what should we keep doing, what should we celebrate, where did we make progress)?
- What could have been better (where did we have problems, what was frustrating to us or others, where/how could we have made a better result)?
- What was lacking (what was missing, what held us back, what would have been ideal that we didn’t have/do/use)?
- What have we learned (and what would we try differently next time)?

We considered these questions for each of five areas: detection research (WP2 and WP5), response research (WP3 and WP6), road user behaviour research (WP4), dissemination (WP7), and project management and any other topics.

Internal praise is not reproduced here, but positives which may have wider usefulness include:

- A "How Now Wow" matrix was considered a useful tool to compare and present diverse research ideas.
- Pictorial storyboards (of the developing traffic situation and its management) were considered a useful tool to facilitate discussions (on traffic management operations).
- Virtual reality simulation of driving, with 360 degree viewability and realistic traffic conditions and surroundings, was considered a useful tool to elicit feedback on driver behaviour, and the pre-determined vehicle path ensured that the stopped vehicle was encountered in the expected way (although the possible additional value we would have gained by allowing the driver to change the vehicle trajectory in real time is unknown).
- Online collaboration tools such as mural seem extremely productive ways of substituting for in-person workshops. They were easy and quick to use for all participants without any barriers, easy and fast to prepare without any significant learning time, and they provide a digital record of the discussion.
- A special interest session at ITS congress maximised the number of people engaged on one topic at the same time.

COVID-19 impacted the project, but that is such an unprecedented occurence that we have not noted the individual impacts and lessons here. Further lessons learned from challenges experienced on the project include these:

- It is a challenge to find an agile iterative way of delivering a CEDR research project. In hindsight our proposed methodology was not ideally agile or iterative – each workpackage produced its final deliverable with few interim technical deliveries that would have facilitated shaping of succeeding work through feedback and prioritisation. We gave regular management reports, but not regular technical deliveries. However simply making many fine-grained technical deliveries may not by itself succeed, because the CEDR Programme Executive Board has limited time to assess and give feedback. Furthermore agile deliveries aim to focus on the highest value priorities, yet in trans-national research with many funding countries, what is most valuable is likely to vary across countries. This topic seems worthy of further consideration beyond the SHADAR project.

- When conducting experiments that need responses from many individual participants, while it is obvious that processing unconstrained oral responses will require more effort than processing predetermined limited choices, the difference was more significant than we had anticipated. We recorded, transcribed, translated, and analysed all oral responses in the first set of VR simulations, but found it just as useful and much more practical to record and process pre-determined limited choices in the second set.
- It could be helpful to all parties to establish in the contract a feedback and approval time limit for all deliveries that are payment milestones. The contract does this for the final report only.
- Despite our positive experience with online collaboration tools in workshops, the basic ongoing file sharing and communication tools are still not ideal for all users across different organisations. SharePoint worked for most but not all participants (having multiple accounts and identities created issues for some), so although it was our primary method of file sharing we also had to resort to email. Despite an initial intention to also use MS Teams for textual discussions we decided against that due to experience of difficulty that using Teams from multiple organisations at the same time can generate for some users.
- The value and cost of publication in scientific journals has changed in this century – this is not a recent development but was the first time that our team had to face this recently. Scientific journals typically allow both "open access" (available on the Internet) publications and publications for subscribers only. For most scientific journals open access requires a fee, typically around $2000, although it can be higher for leading journals from big publishers. Subscriber-only publication can be without fees, but with the typical expectation of many researchers and consultants being to find research through Internet search, a subscription-only publication seems likely to reach a much smaller audience.

5 Next steps

This final report completes the work of the SHADAR project, but its results suggest both action and further research.

The action can be considered by each road authority individually, using the key findings reported in section 2 to consider use of the most valuable techniques – such as implementing a data fusion system, harnessing various connected vehicle sources, or educating drivers – according to the needs and priorities of the country.

The following items highlight further research topics suggested by SHADAR research results.

- Find the most effective methods of driver education on stopped vehicle hazards, which will maximise the compliance with the best safe practices.
- Use a significant quantity of real eCall data to validate the estimates in SHADAR research and therefore confirm the value of automated eCall MSD processing.
- Aquire larger volumes of real radar stopped vehicle data with full context, and use to confirm the significance of techniques explored by SHADAR.
- (For countries other than Netherlands where SHADAR focussed its Waze study) Capture Waze data sets and perform similar tests to confirm the value of the data source.
- (For countries other than covered by the reported DfRS study) Capture Data for Roads Safety data sets and test to confirm the value of the data source.
- Conduct ground truth studies on stopped vehicle detection performrmance, especially using multiple sources covering the same place and time, and share results with further insights into the usefulness of combinations of particular kinds of sources.
- Investigate the feasibility and value of post-eCall communcation between emergency responders and affected vehicles.
- As part of growing partnerships with in-vehicle service providers, explore the feasibility of cooperation patterns beyond reciprocal data exchange, but consideration of the ongoing funding pattern should not be deferred.

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